C R O C K E R   N U C L E A R   L A B O R A T O R Y

UNIVERSITY OF CALIFORNIA, DAVIS

FINAL REPORT

to the

CALIFORNIA AIR RESOURCES BOARD

CONTRACT ARB-502

CONTRIBUTION OF FREEWAY TRAFFIC TO AIRBORNE PARTICULATE MATTER

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Principal Investigator

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(Abbreviated Version)

Personnel and Acknowledgements

Although much of this work was done in a cooperative fashion by all project members involved, especially the senior staff, most personnel contributed strongly to specific areas of the work, and we would like to acknowledge their contributions in detail.

TAC and PJF

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Harvey Thibeau Jerry Stadel	Accelerator Electronics	Development of Beam Sweeper

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We wish to express our appreciation to the Institute of Ecology of the University of California, Davis, whose support has allowed a much wider distribution of this report than would otherwise have been the case.

Contribution of Freeway Traffic to Airborne Particulate Matter

Summary and Conclusions

Particulate matter, both liquid and solid, was collected both upwind and downwind of four sites along Southern California freeways in order to investigate the origins and dispersal of particulate matter associated with heavy vehicular traffic. Asymmetric arrays of five stage inertial impactors (Lundgren) including back-up filters were placed across the roadways, generally with one station upwind and five stations downwind, extending up to 530 ft. (160 meters) from the median of the right of way. Samples were collected during 9 days between February and August, 1972, totalling about 600 hours of sampling. The freeway sites were selected so as to coincide as much as possible with the California Department of Highways study, "Air Pollution and Roadway Location, Design and Operation," located on the instrumented "42-mile loop," and included freeway sections at-grade, cut, and filled. Samples were obtained in such a way as to average over two hour periods, although some information was generated with 2 minute time resolution. About 3,000 samples were analyzed for content of elements heavier than sodium by ion-excited x-ray emission (IEXE) at the Crocker Nuclear Laboratory of the University of California, Davis. Selected samples were also analyzed by x-ray fluorescence, electron microscopy, the electron microprobe, alpha-scattering, optical density, and electron spectroscopy for chemical analysis (ESCA), with the last type of analysis being performed at the Lawrence Berkeley Laboratory. The results were combined with weather data generated by the U.S. Department of Commerce, the Los Angeles Air Pollution Control District, the California Division of Highways, and our own personnel, in order to study dispersal patterns from the roadways. Values from the upwind station were used to isolate the contribution of freeway traffic from other sources. Numerous samples of automotive expendables were collected and analyzed for elemental content in order to aid interpretation of sources. Modelling of dispersal patterns was attempted in some highway configurations, using models generated by the Atmospheric Sciences group at Davis. It should be emphasized at this time that freeway traffic was chosen as the target for this study because of the very large number of vehicles using the roadway, the excellent support afforded this study by the California Division of Highways

through their own environmental program, and the traffic data generated by instrumentation on the "42-mile loop." It is in no way implied that freeways are more polluting per vehicle mile than other roadways, but no data in this report bears upon the question. The results presented here should apply equally well to any concrete roadway with steady, high speed traffic, with the possible exception of collective effects involving heat. Major conclusions are given below:

1. Although precise, quantitative determinations of all sources of particulate matter from vehicular traffic cannot be made at this time, the observed particulate matter could be fitted reasonably well by estimated use of automotive expendables.

2. Combustion products of gasoline, including lead, bromine, chlorine, and sulfur, provided about 2/3 of all elements heavier than sodium observed in the particulate matter.

3. About 60% of the elements heavier than sodium that were seen in particulates consisted of particles less than 5 microns. Combustion products dominated this latter class, with most mass occurring below 0.5 microns.

4. Dispersion of particulates was dominated by wind conditions, with high values of particulate mass per vehicle mile occurring in calm periods in near-freeway locations.

5. Freeway configuration played a striking role in particulate dispersal in moderate wind conditions. For example, lead levels in the air for particles smaller than 5 microns in aerodynamic diameter in moderate wind conditions at a location 330 feet (100 meters) from the freeway median were:

Freeway Configuration	Wind	Lead Levels ($\mu g/m^3$) (per 5000 veh./hr)
Cut section (-30 ft)	Transverse or Parallel	0.3
At-grade section	Transverse	1.4
Fill section (+20 ft)	Transverse	3.1

6. Lead levels at 330 ft (100 meters) downwind of the median of a fill section freeway averaged about 10 $\mu g/m^3$ during a 24 hour period in August, 1972.

7. Using emitted lead values from the literature, and dispersion models developed at Davis, lead levels from the at-grade freeway section could be predicted to high precision. Qualitative agreement was obtained for dispersal patterns from the fill section freeway, while no fits were attempted for cut-section freeways due to limitations in the model.

Recommendations for Further Study

1. High priority should be given to investigating the effects of the planned introduction of catalytic afterburners on sulfur in automotive exhaust originating from residual sulfur in gasoline. The possibility of major increases in particulate sulfur levels, especially in the south coast basin, due to more efficient gas to particulate conversion in automotive exhaust, needs to be evaluated as soon as possible.

2. Particulate production of fuel combustion should be routinely studied, with emphasis on the role of sulfur and changes that may be occurring in fuel composition.

3. Long term monitoring of particulate levels should be undertaken at locations suspected of high lead particulate levels from nearby roadways.

4. Opportunities exist for epidemiological studies in areas stressed by automotive pollutants.

5. Studies should be made of airborne particulate matter from heavily travelled surface streets, especially involving stop and go traffic.

6. Identification of sources of automotive particulates could be greatly aided by a systematic attempt to characterize all expendables associated with cars, especially tires, brake linings, and exhaust system components, by elemental and chemical composition. This program would also prevent the introduction of new pollutants caused by changes in manufacturing process, oil and gas additives, and pollution reduction equipment such as catalytic afterburners.

7. The mechanisms involved in dispersion of freeway particulates, especially mechanisms involving heat and freeway-configuration, could be better studied with improved meteorological instrumentation.

(There are references to Figures and Tables that do not occur in this abbreviated version of the report, but only in the full text).

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I. *INTRODUCTION*

The purpose of this study was to examine the contribution of freeway traffic to airborne particulate matter, especially in the immediate vicinity of a freeway, and to identify the origins of the material.

In order to accomplish this end, it was necessary first to obtain information on the source of the particulates - freeway traffic. This information was available from the California Division of Highways instrumented freeway sections in the Los Angeles basin - the "42 mile loop" (see Figure #1). Information on traffic volume and average speed was available at about half mile intervals on the loop through sensing loops imbedded in the road, and was processed by computer to generate tables of such data with a time resolution of 5 minutes. Examples of such information are given in Figures #2 and #3. Information on traffic mix was obtained through traffic counts done by UCD personnel and some photographs. Sites along this loop were selected in order to study the effect of freeway configuration (at grade, cut and fill) and meteorology on the production and dispersal of freeway generated particulate. Site descriptions are given in Figures #4, #5, #6 and #7. Whenever possible, these sites were selected so as to maximize overlap with a parallel study run by the California Division of Highways, Air Pollution and Roadway Location, Design and Operation. The Division of Highways study involved considerable gas analysis (including information on vertical profiles of pollutants) and included local meteorological information. The cooperation of the Division of Highways staff in sharing information and facilities is gratefully acknowledged. Strong local particulate sources were avoided whenever possible, and generally residential neighborhoods dominated the near freeway vicinity. In cut sections, the existence of pedestrian overcrossings simplified sample collection. Sample collection was accomplished through the use of five stage inertial impactors of the Lundgren design (Appendix A). Eight identical units could be operated simultaneously, collecting particulate samples as a function of particle effective diameter on parafin coated thin mylar substrates and Whatman 41 cellulose filters. Nominal effective diameters of the five collection stages for unit density spheres corresponded to: Stage 1 - $\sim 100\mu$ to 18μ; Stage 2 - 18μ to 5μ; Stage 3 - 5μ to 1.8μ; Stage 4 - 1.8μ to 0.5μ; Stage 5 (filter) - $< 0.5\mu$. Both liquid and solid aerosols were collected.

FIGURE 1

STUDY OF FREEWAY PARTICULATES

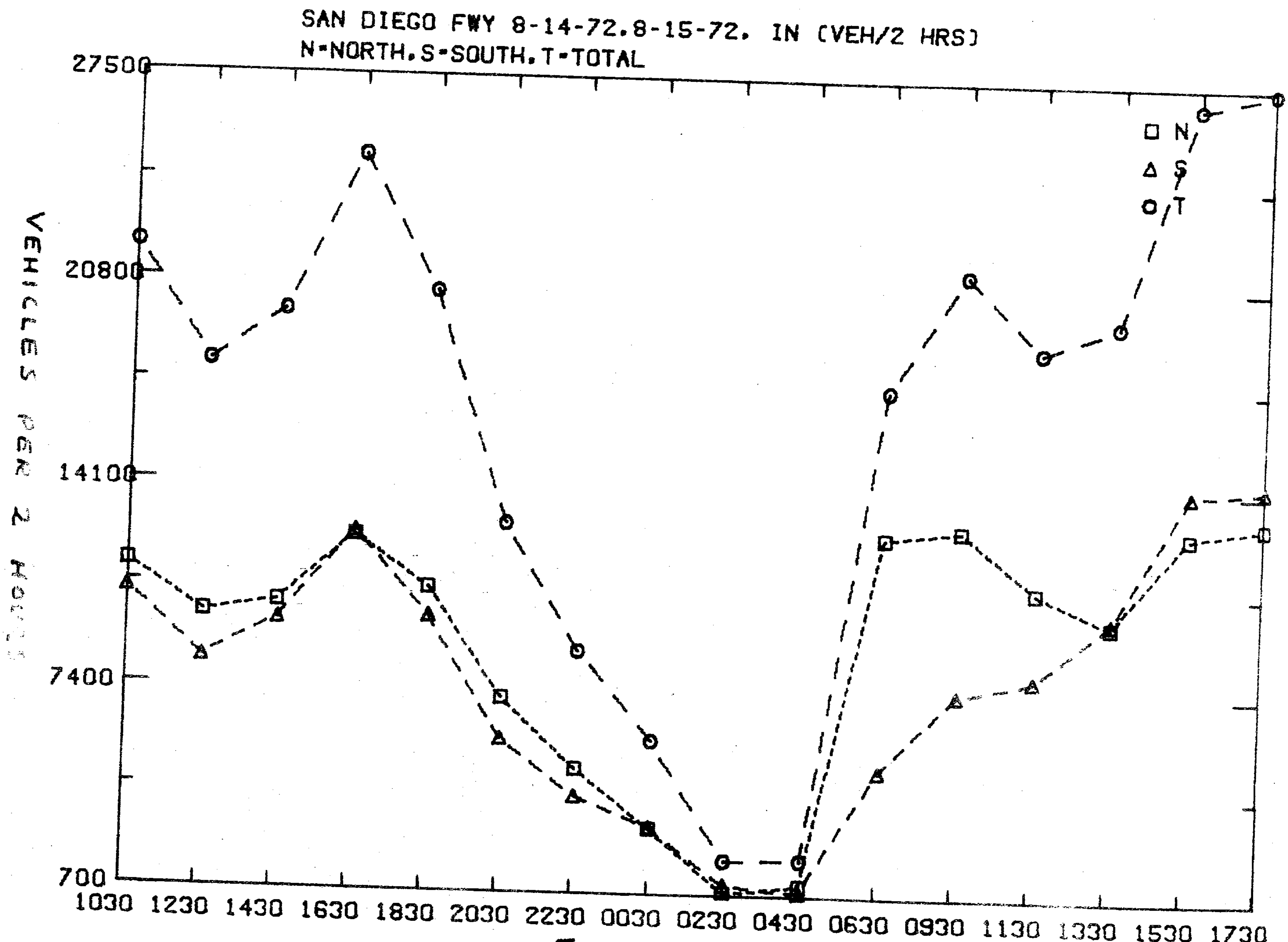
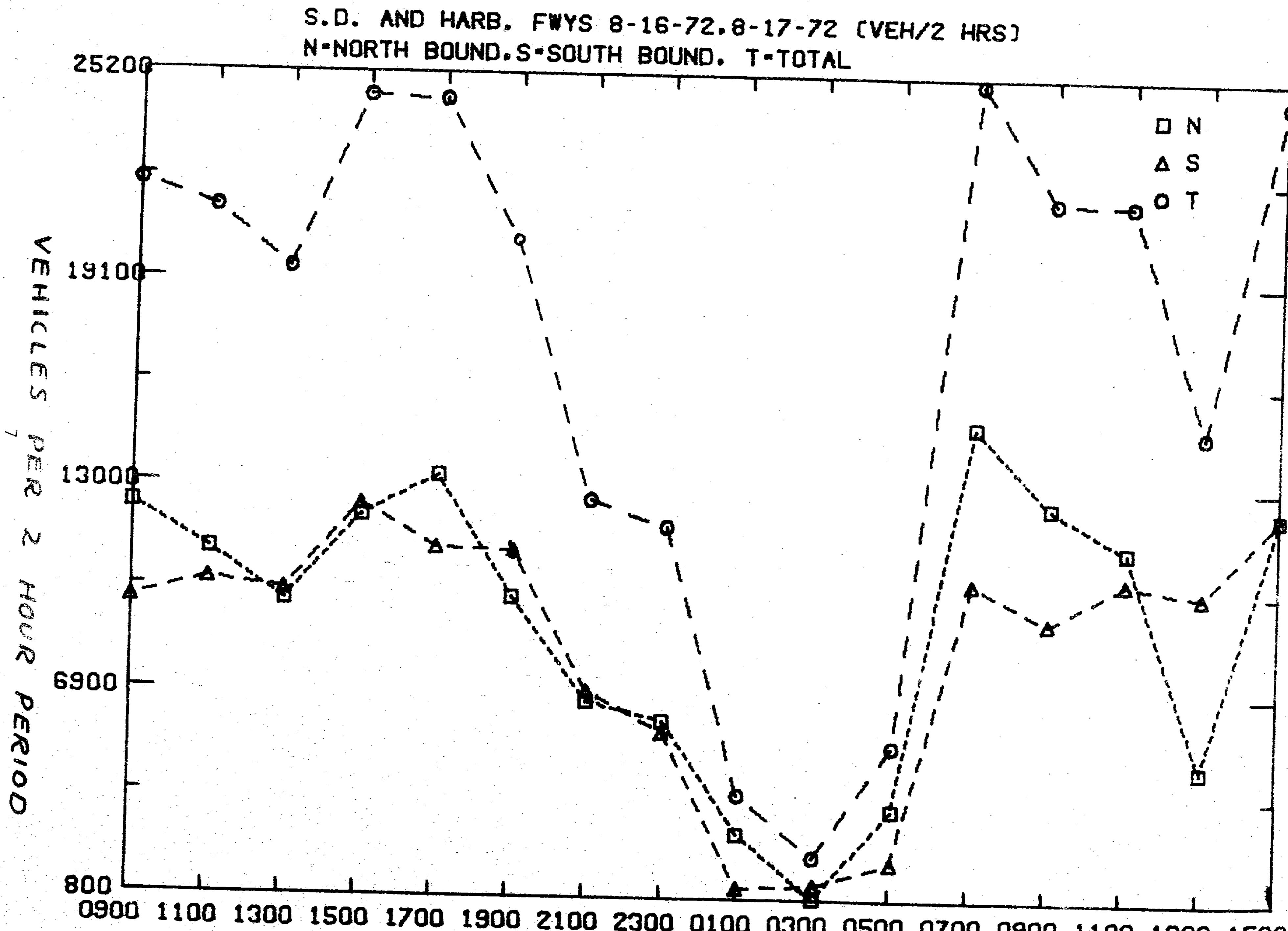
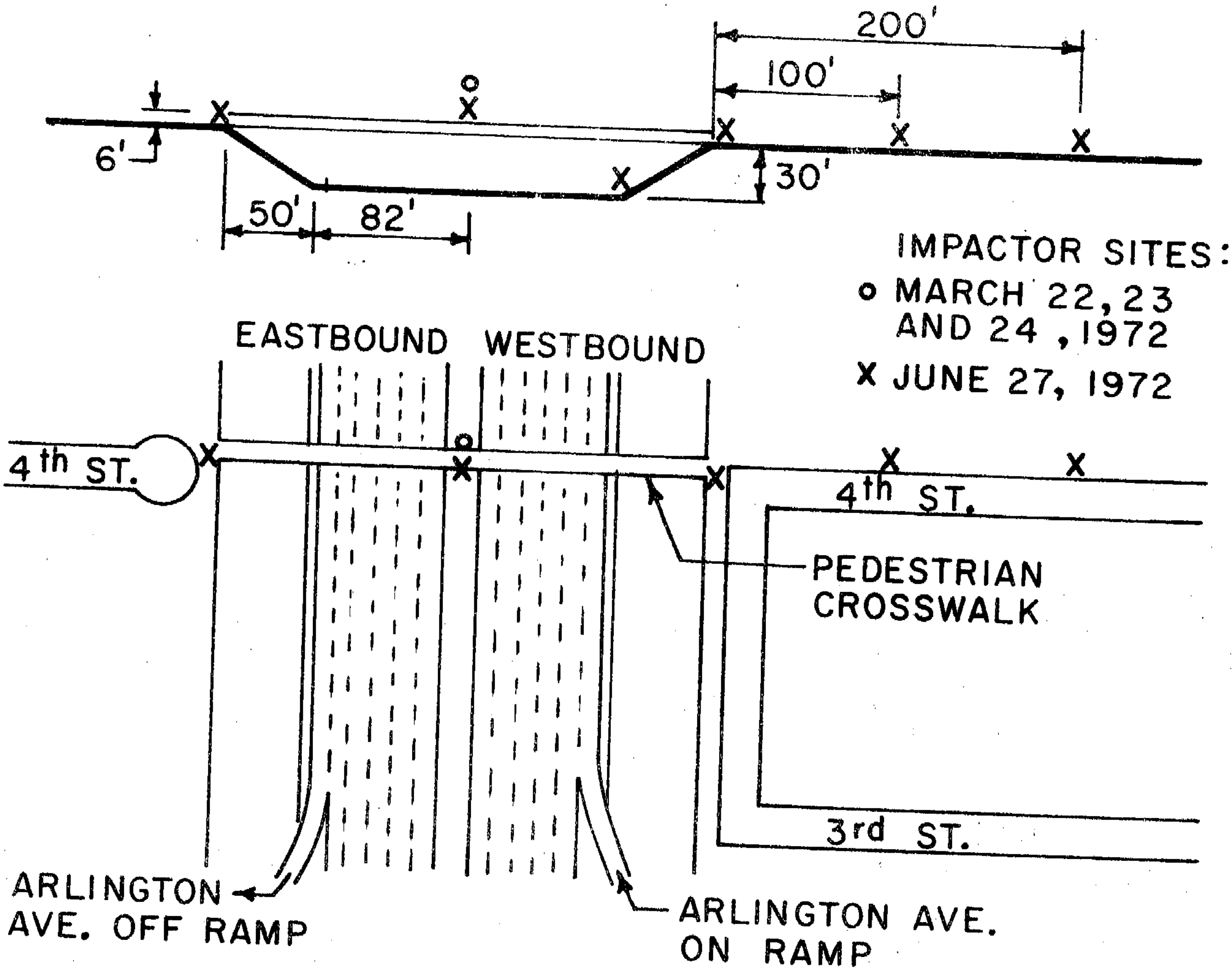

SAN DIEGO FWY 8-14-72.8-15-72. IN (VEH/2 HRS)
N-NORTH.S-SOUTH.T-TOTAL
27500
20800
14100
7400
700
VEHICLES PER 2 HOURS
1030 1230 1430 1630 1830 2030 2230 0030 0230 0430 0630 0930 1130 1330 1530 1730
TIME OF DAY
N
S
T

FIGURE 2



S.D. AND HARB. FWYS 8-16-72.8-17-72 (VEH/2 HRS)
N=NORTH BOUND. S=SOUTH BOUND. T=TOTAL
N
S
T
25200
19100
13000
6900
800
VEHICLES PER 2 HOUR PERIOD
0900 1100 1300 1500 1700 1900 2100 2300 0100 0300 0500 0700 0900 1100 1300 1500
TIME OF DAY

FIGURE 3

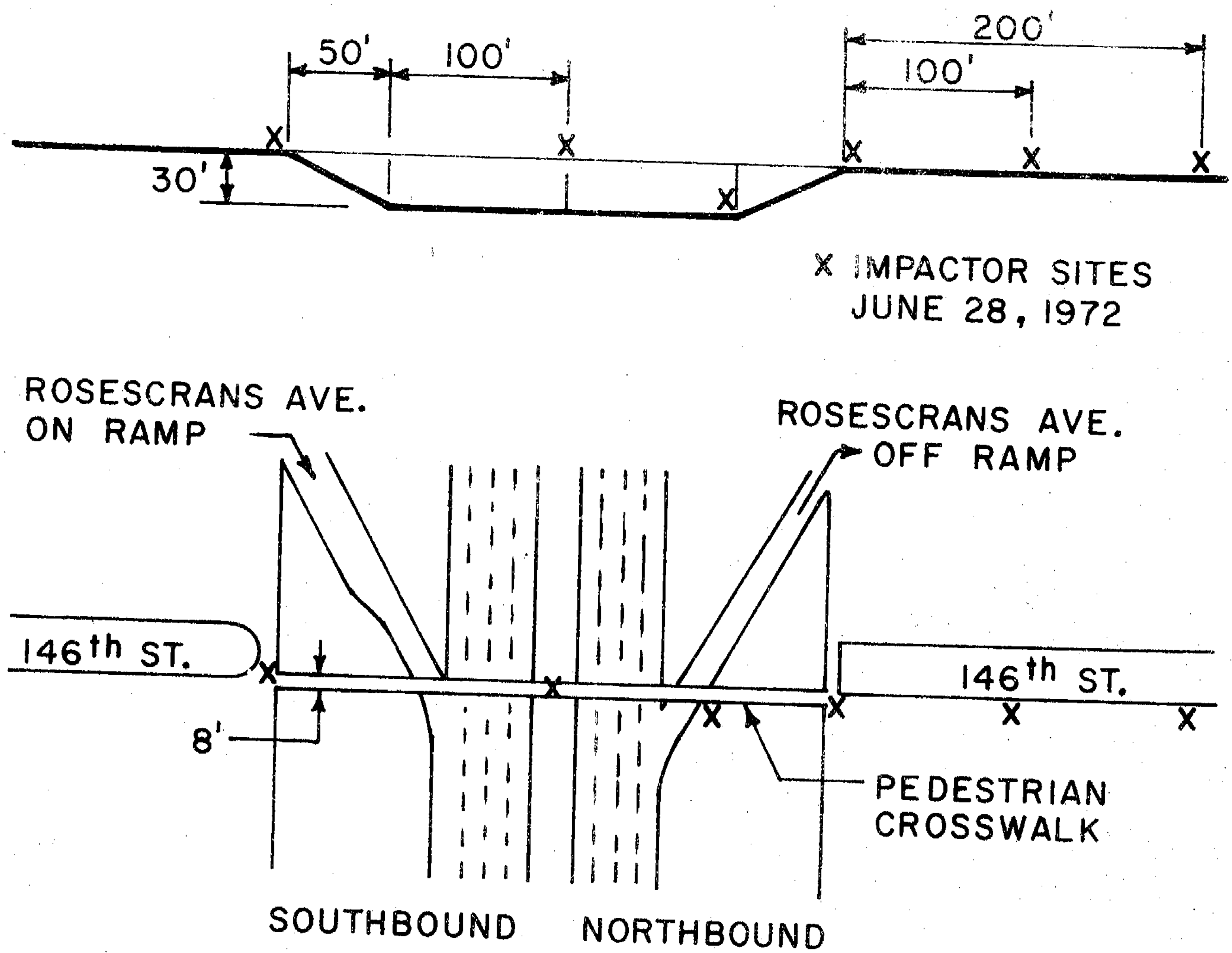


SITE #1 (SM)

SANTA MONICA FREEWAY NEAR 4th ST.

3/22-24/72 and 6/27/72

FIGURE 4

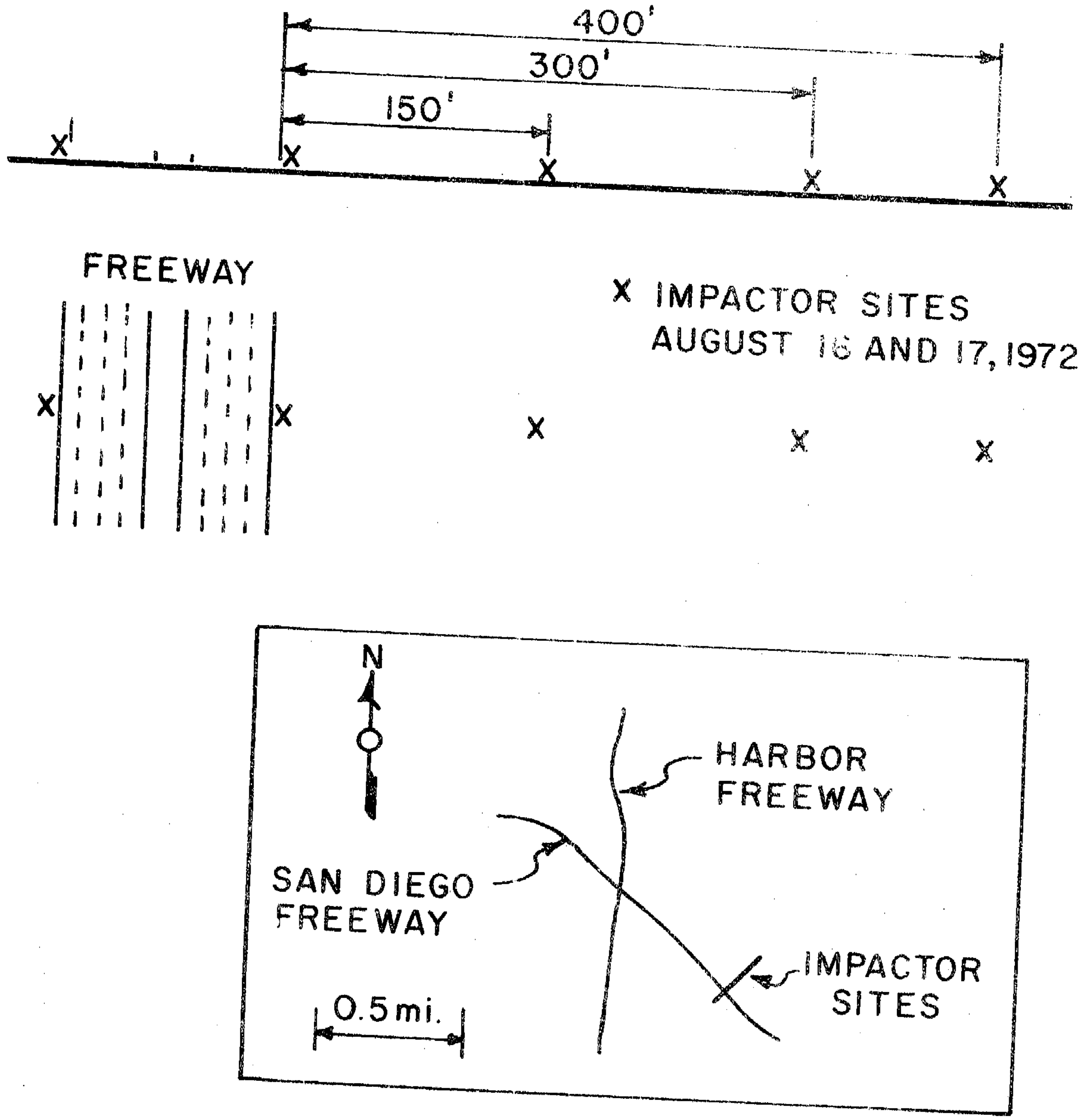


SITE #2 (H)

HARBOR FREEWAY NEAR 146th ST.

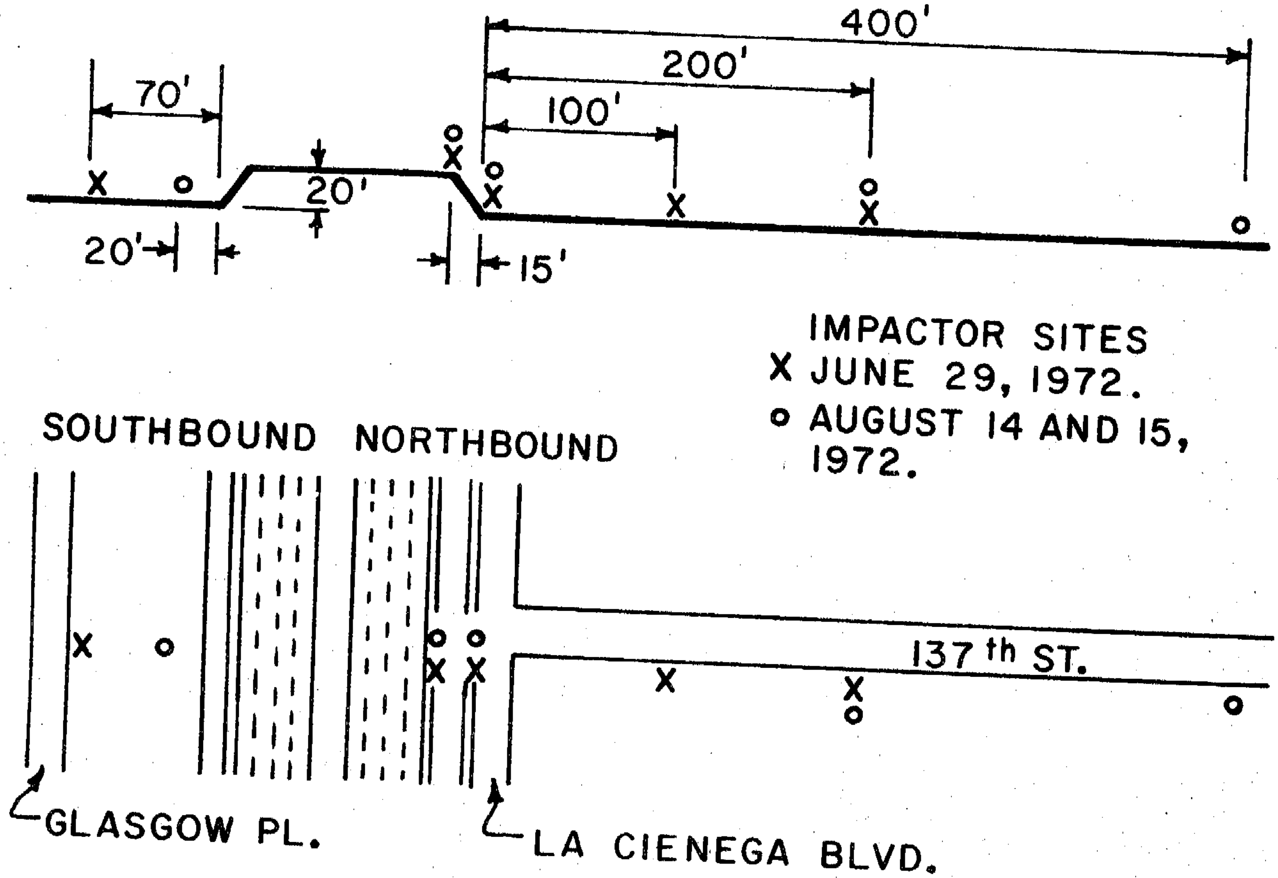
6/28/72

FIGURE 5



SITE # 3 (SDH)

SAN DIEGO FREEWAY NEAR HARBOR
8/16-17/72
FIGURE 6



SITE #4 (SD)

SAN DIEGO FREEWAY NEAR 137 th ST.
6/29/72 and 8/14-15/72

FIGURE 7

These units were placed across the freeways in an asymmetric array, with one unit in what was usually an upwind direction and the rest at various distances downwind of the freeway. The units were operated on a continuous basis for as long as three days at a time. A description of the sampling episode is given in Table #1. Samples from the slowly rotating drums (1 rev/24 hrs) were cut into two hour segments, and the after filters (Stage 5) were changed every two hours. The samples were analyzed generally by ion - induced x-ray emission (IEXE)[1,2,3,4] although some were also analyzed by x-ray fluorescence (XRF)[5], electron spectroscopy for chemical analysis (ESCA)[6], and alpha scattering for very light elements[3] (Appendix B). About 30 samples were also examined by a scanning electron microscope (SEM) and a few samples were studied through use of an electron microprobe, which could examine the elemental composition of individual particles. All analyses except the ESCA (done at the Lawrence Berkeley Laboratory) were performed at UCD.

Weather data were generated on-site by UCD personnel via hand-held instruments (wind direction and velocity). In addition, weather information was obtained from the Division of Highways units at most sites as well as from the National Weather Service at the Los Angeles International Airport.

Finally, in order to aid in interpretation of the results, elemental analyses of automotive components were performed by IEXE and XRF, and a large number of automotive particulate samples were collected and analyzed from various makes of automobile and various types of gasoline. A static mixing chamber was used on two occasions to examine automotive particulates from a car running under fast idle conditions (without load).

TABLE 1

Sample Collection Episodes

Site	# Units		From			To	
Bay Bridge	1 Lundgren		0852	3/9/72		1040	3/9/72
	1 Davis 2-stage		"	"		"	"
LA site 1	1 Lundgren	Wed.	1100	3/22/72	Fri.	1800	3/24/72
LA sites 2,3,4,8	1 Lungdren (short samples)		10:00	3/24/72		1300	3/24/72
Interstate 80	5 Lundgrens		0945	6/21/72		1130	6/21/72
LA site 1	6 Lundgrens	Tu.	0830	6/27/72		1830	6/27/72
LA site 2	6 Lundgrens	Wed.	0630	6/28/72		1800	6/28/72
LA site 4	5 Lundgrens	Th.	0600	6/29/72		1600	6/29/72
LA site 4	5 Lundgrens	Mon.	0930	8/14/72	Tu.	1630	8/15/72
LA site 3	5 Lundgrens	Wed.	0800	8/16/72	Th.	1500	8/17/72

June - March Samples of Source Material

October - January Samples of Exhaust Particulates

Other studies using this equipment included studies of the geothermal area near Geyserville, a feed lot in Visalia, particulates in Davis air, August 1972, a number of potential toxic metal sources and natural background studies. In addition, considerable use was made of the system to evaluate the collection process in inertial impactors.

II. PRODUCTION OF FREEWAY PARTICULATES

A. Morphology

Freeway particulates, like all natural particulates, are highly diverse in size, shape, and chemical composition. The ensemble of these particles constitute the freeway aerosol. Any attempt to categorize this aerosol by a few parameters such as size and shape is of necessity a crude approximation to reality. Nevertheless, some information can be gained in an operational sense by doing this, especially since some effects of the aerosol are independent of their precise morphology of the individual particles.

1. Aerodynamic Size

Particles can be characterized as having an effective aerodynamic size that governs their behavior in air streams and thus is important for generation of settling rates, impaction parameters, and filtration properties[7].

Information on the aerodynamic size of the particulates is generated by collecting the particles on the five stages of the Lundgren[8] impactors (see Appendix A). These devices generate cutpoints corresponding to 50% capture efficiency for the particles, in terms of an effective diameter, D_{eff}, based on a sphere of density ρ. Values for these cutpoints for the impactors, used in this study, operated at 4 ft^3/min, are: (approx.)

For	$\rho=1$	$\rho=2$	$\rho=3$
Stage #1	18μ*	10μ	8μ
Stage #2	5μ	3μ	2.5μ
Stage #3	1.8μ	1μ	0.8μ
Stage #4	0.5μ	0.3μ	0.25μ

The cutpoints vary about as $\rho_p D_{eff}^2$ for fixed geometry, velocity and air viscosity[7]. If the 50% collection efficiency cutpoint occurs at D_{eff}, then 20% occurs at about 0.8 D_{eff} and 80% at about 1.2 D_{eff}.

* Microns (μ) will be used instead of μm (10^{-6}m) throughout this report.

Ignoring this variation in collection efficiency, then for spheres of unit density, the following particle diameters were collected on each stage.

Stage #1	18μ	to ∿	100μ *
Stage #2	5μ	to	18μ
Stage #3	1.8μ	to	5μ
Stage #4	0.5μ	to	1.8μ
Filter	<0.5μ		

The filters used in this study were Whatman 41 disks, 90 mm diameter. This filter was convenient in that it allowed the impactors to be run at rated flow rate, and because this material possessed low values of contamination for elements sodium and heavier. It had one major disadvantage, however. Small particles became deeply buried in this filter medium, so that the x-ray based analysis suffered from a major correction factor for light elements[1]. Normally, only elements iron and heavier are quoted from the filters, since the maximum correction for these elements is 10%. However, light elements can be observed semi-quantitatively, and these observations will be mentioned when appropriate. This filter medium also can allow some penetration of small particles under certain conditions, but this effect is thought not to have been significant. (Appendix A)

All samples were individually analyzed for elemental content, giving information on which freeway components exist in what aerodynamic sizes. This information is useful for determining sources as well as for calculating dispersion into near-freeway and remote areas. In many cases, since particles <5μ Deff possess negligible settling velocities, stages #3, #4, and the filter were summed after analysis. Stages #1 and #2 were likewise summed to isolate the fraction that pcssessed significant settling velocities, Deff <5μ.

(Pages 16, 17, 18, 19 and 20 in the full text relate information on physical sizes and shapes of particles obtained from scanning electron microscopy. The conclusions are:

1. The impactors operated as designed in separating particles by size, and,

2. The effective densities of particles were highly variable, with low densities ($\rho \leq 1$) occurring for small particles.)

* Samplers were generally faced into the prevailing strong winds in a quasi-isokinetic sampling mode. Since the inlet air velocity was about 2 mi/hr, this allowed a few very large particles to be seen on Stage #1.

B. Elemental and Chemical Composition

Further information on freeway particulates can be obtained by using elemental information from upwind versus downwind locations near a freeway to identify those elements enhanced by the presence of the freeway. This was accomplished by isolating all freeway cross-cut data from the upwind and downwind sampling locations such that:

1. The wind direction was from the upwind station towards the downwind stations, with an average angular variation of no more than ±45° from the sampling axis over a 2 hr. period.

2. The wind velocity was at least 2 mile/hr. These conditions were met by 25 two-hour periods during June and August for sampling sites #2, #3, and #4.

Samples taken in these conditions were analyzed for elemental content by x-ray based methods (mainly IEXE - see Appendix B). Elements sodium and heavier could have been seen if present in amounts more than about 5 to 25 nanograms per cubic meter of air (for Stages #1, #2, #3, and #4) and, for elements iron and heavier, in amounts greater than about 500 ng/m^3 on the filters*. An example of one such analysis is shown in Figures 9 and 10 for a 1.8μ to 5μ cut (Stage #3) at the San Diego Freeway. Major elemental interferences were subtracted (Br L line from Al, Pb M line from S, and Kα/Kβ interferences above Ca). The result was a table of elements for each stage and filter, with amounts and estimated absolute errors.

The data were then generally combined into summations based upon particle size, with particles with $D_{eff} > 5\mu$ in one category (Stages #1 and #2) and $D_{eff} < 5\mu$ in another category (Stages #3 and #4, plus the after filter). This was convenient from the point of view of sedimentation effects as well as particulate sources, since elemental contents within these categories were often similar. Note that no elements lighter than iron are included from the after filters, since matrix effects in the Whatman 41 filters were not well enough determined to be used to extract quantitative values for these elements. No major qualitative differences in composition were generally observed, however, between Stage #4 and the after filters.

The average enhancement of the downwind station relative to the upwind station was then determined for all elements observed by subtracting the upwind value from the downwind value, normalizing to a 5000 vehicles/hour traffic flow rate in each two hour interval, with a correction for Site #3 (see Sec.III.D).

* Detailed sensitivities are given in Appendix B.

FIGURE 9
Analysis Code as of 10/20/72

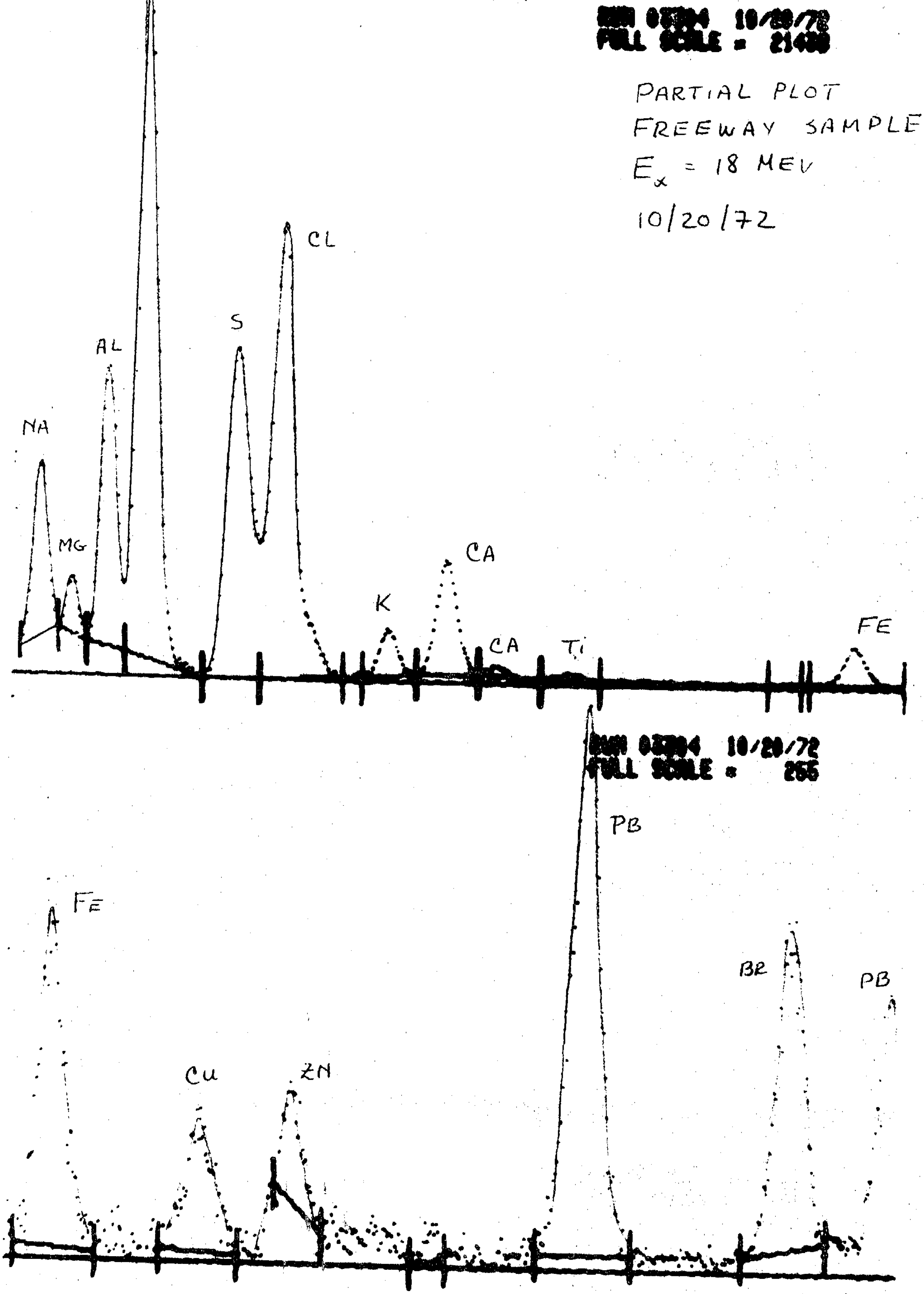
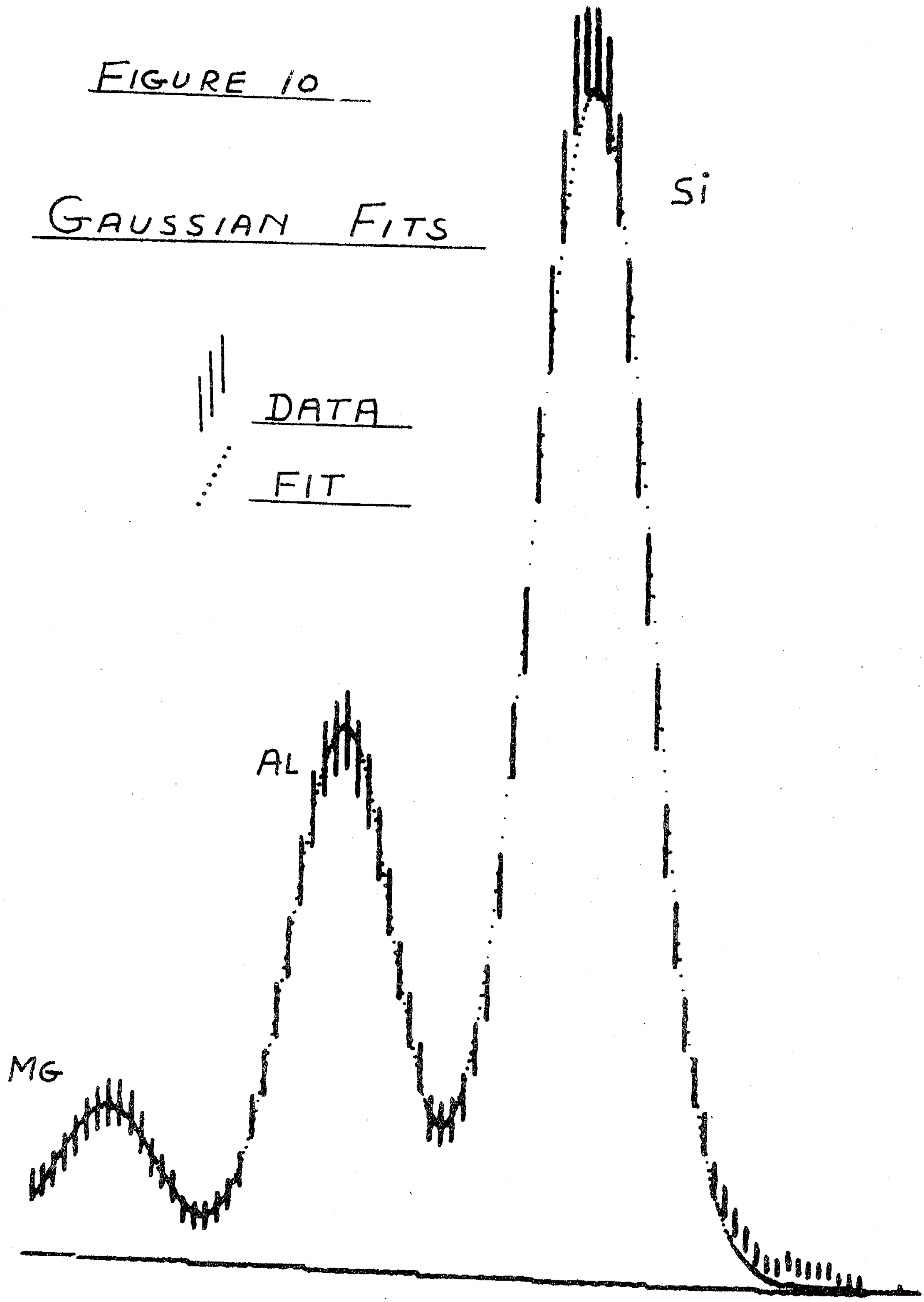


FIGURE 10

GAUSSIAN FITS



An example of one cross cut used in this procedure is given in Figures 11, 12, 13, 14, and 15. In this particular case, 1/2 the value for these elements at 400 ft. was chosen as representing an effective background, since the upwind station appears to have been subject to some freeway influence. The question of the statistical significance of an enhancement is highly dependent upon the value of upwind levels of these elements. As an example, the high Na, Al, Si, S, and Cl values usually encountered at the upwind site demand that the contribution of the freeway has to be major in order to dominate the background. This is despite a conscious effort to locate sampling sites in low background areas of the Los Angeles basin.

The values obtained by the above procedure are given in the first column of Table 3, normalized to the lead value (FWY $<5\mu$, WIND). The variances encountered, due to variation in site and weather, are very large, and these values should not be taken as being more than semi-quantitative.

Another way to approach the problem is to accept data generated in situations in which the freeway source dominates the background aerosol. Such conditions appear to be met when the wind falls to below 1 knot. Very high lead and bromine values are encountered, due to the feeble dispersion possible in these cases, which indicates a strong freeway contribution. Since all sites used in this study were well removed from other known strong local sources, the values recorded are assumed to be predominantly due to the freeway. Traffic on secondary streets was calculated to contribute little to the observed values, especially since most of these calms occurred late at night. The relative values recorded during 11 two-hour calm periods are given in the second column of Table 3 (FWY, $<5\mu$, CALMS).

The third column gives a weighted average for the two previous situations, and these values will be used for the elemental content of freeway particulates $<5\mu$ in future comparisons. The fourth column gives the values for Deff $>5\mu$ for moderate winds. The weighted average of column 3 and column 4 (at about an 90% - 20% weighting) will be used to compare with total particulate production by element, all size ranges, and is given in column 5.

SD AND HARB FWY AVG FOR 8AM-1PM 8-17-72 AMTS/10000 VEH
WIND SOUTH PARTICLE SIZES LESS THAN 5 MICRONS

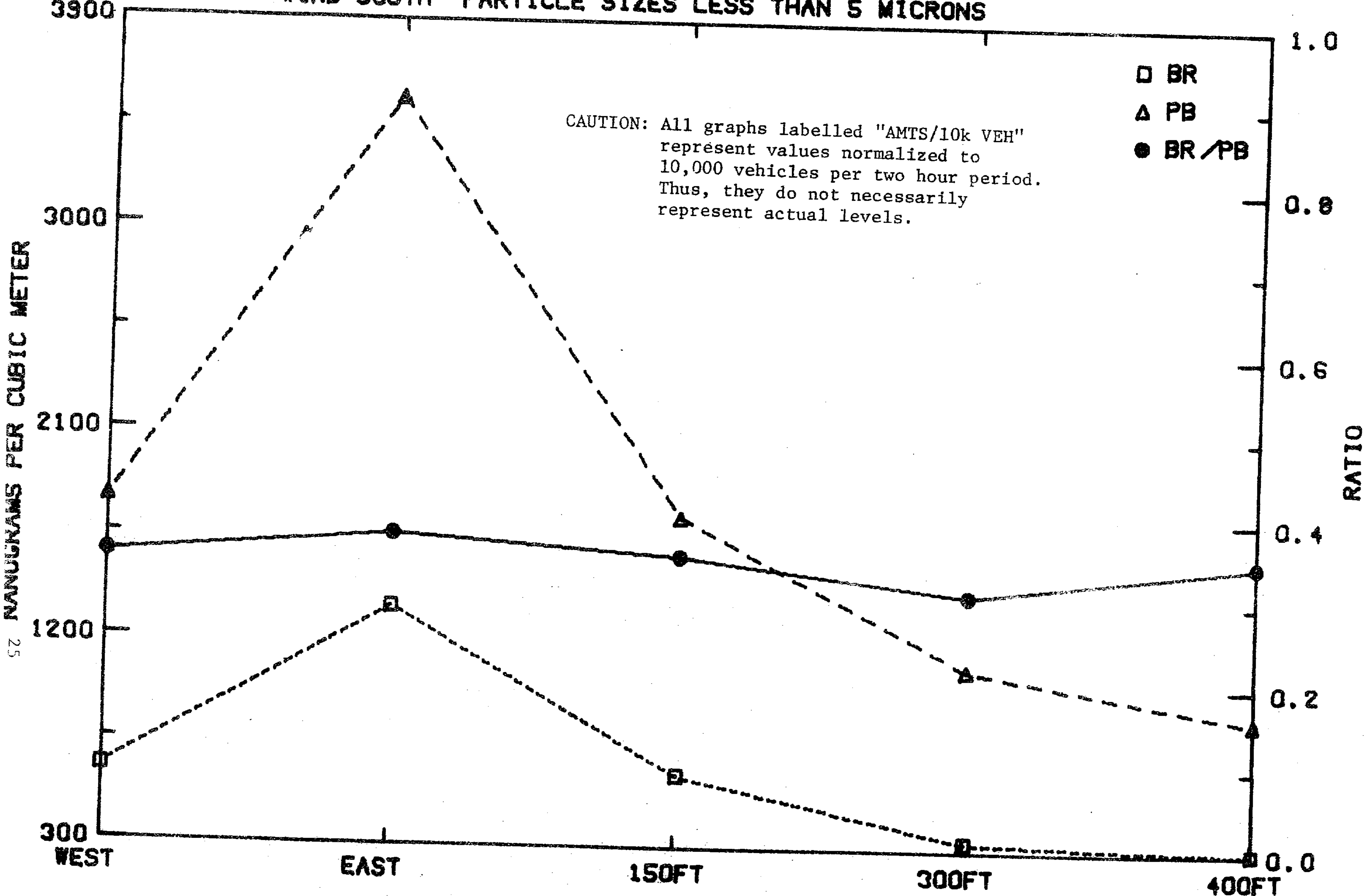


FIGURE 11

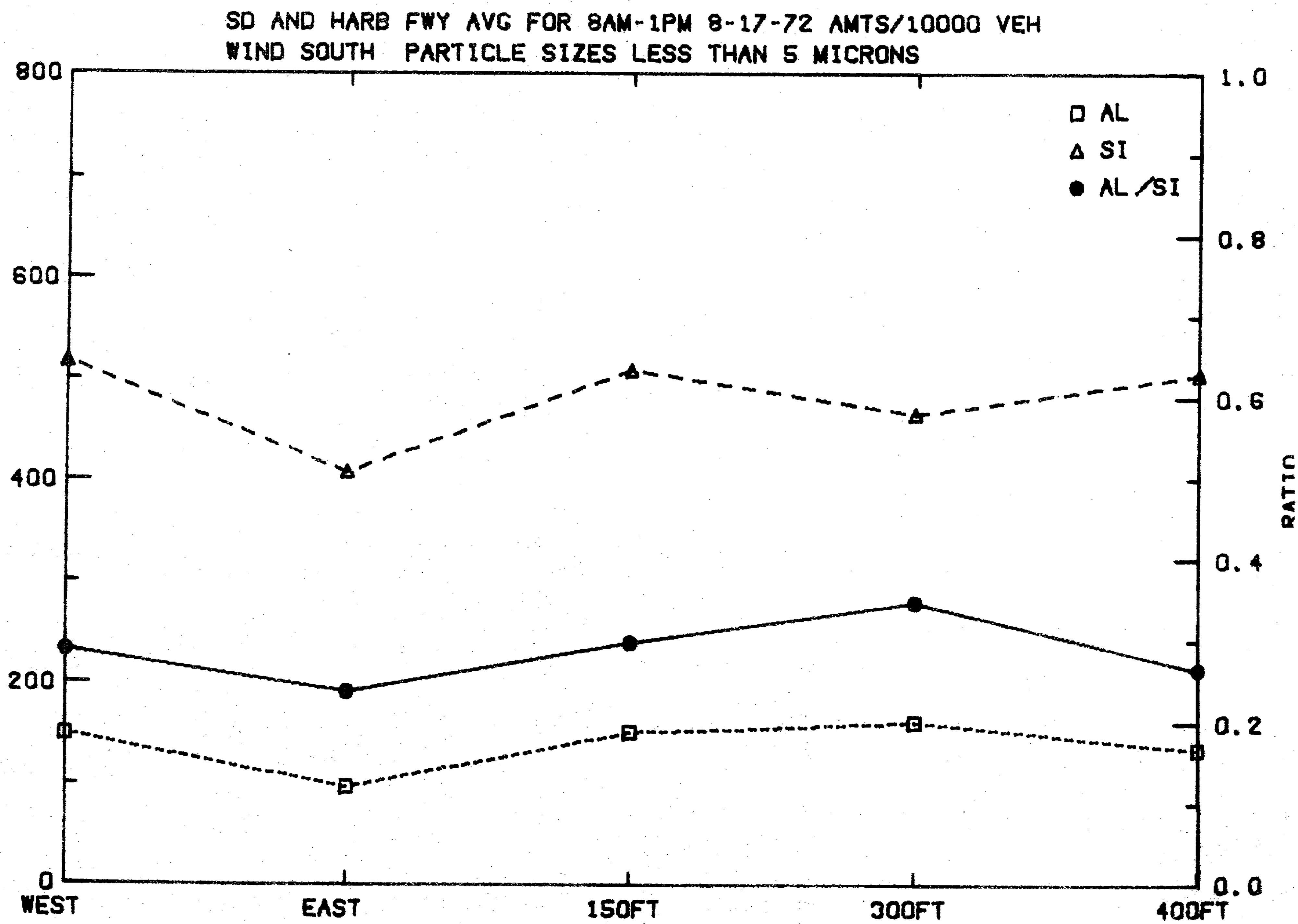

SD AND HARB FWY AVG FOR 8AM-1PM 8-17-72 AMTS/10000 VEH
WIND SOUTH PARTICLE SIZES LESS THAN 5 MICRONS
NANOGRAMS PER CUBIC METER
800
600
400
200
0
RATIO
1.0
0.8
0.6
0.4
0.2
0.0
□ AL
Δ SI
● AL/SI
WEST
EAST
150FT
300FT
400FT

FIGURE 12

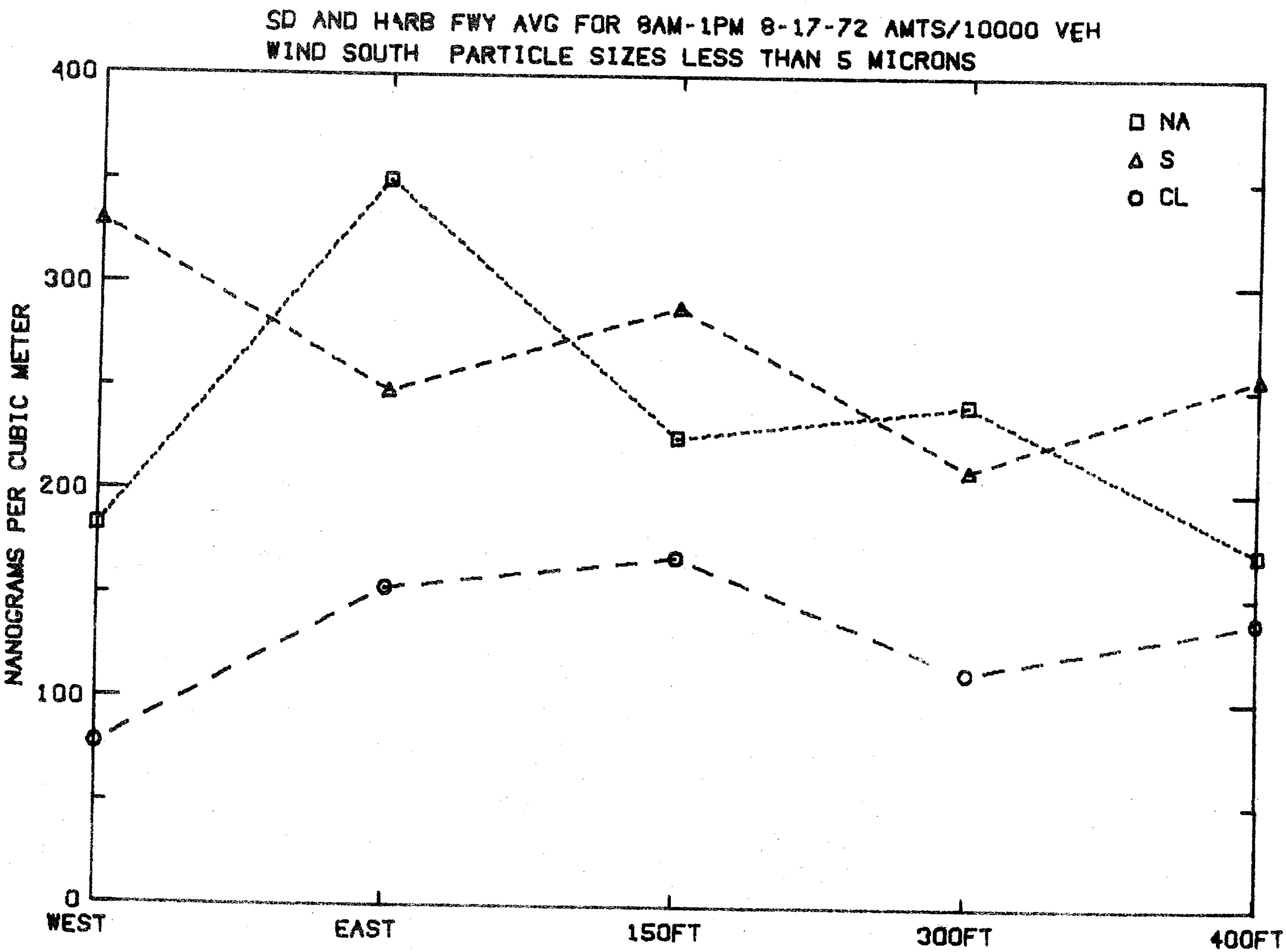

SD AND HARB FWY AVG FOR 8AM-1PM 8-17-72 AMTS/10000 VEH
WIND SOUTH PARTICLE SIZES LESS THAN 5 MICRONS
NA
S
CL
NANOGRAMS PER CUBIC METER
400
300
200
100
0
WEST
EAST
150FT
300FT
400FT

FIGURE 13

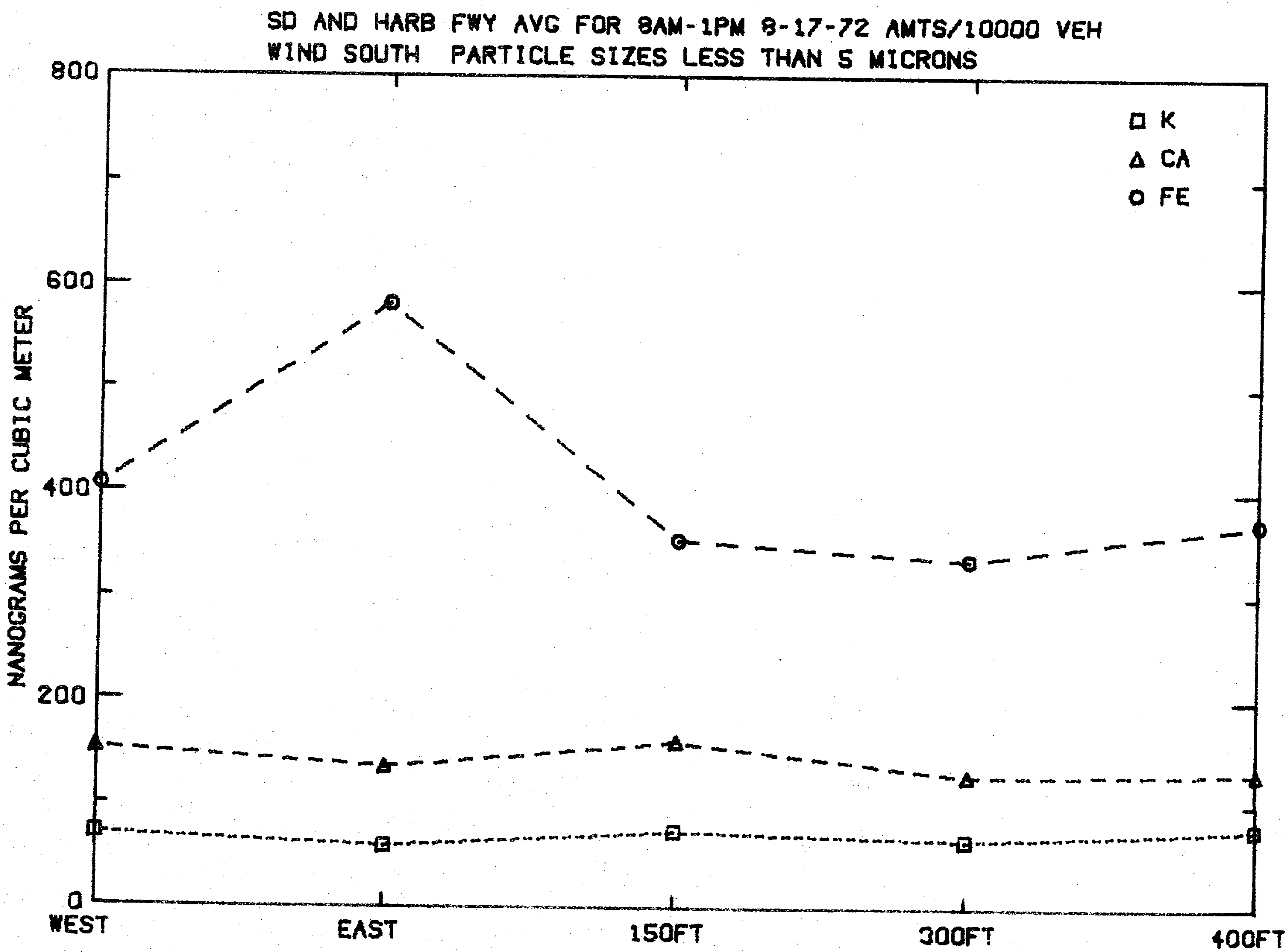

SD AND HARB FWY AVG FOR 8AM-1PM 8-17-72 AMTS/10000 VEH
WIND SOUTH PARTICLE SIZES LESS THAN 5 MICRONS
NANOGRAMS PER CUBIC METER
800
600
400
200
0
WEST
EAST
150FT
300FT
400FT
K
CA
FE

FIGURE 14

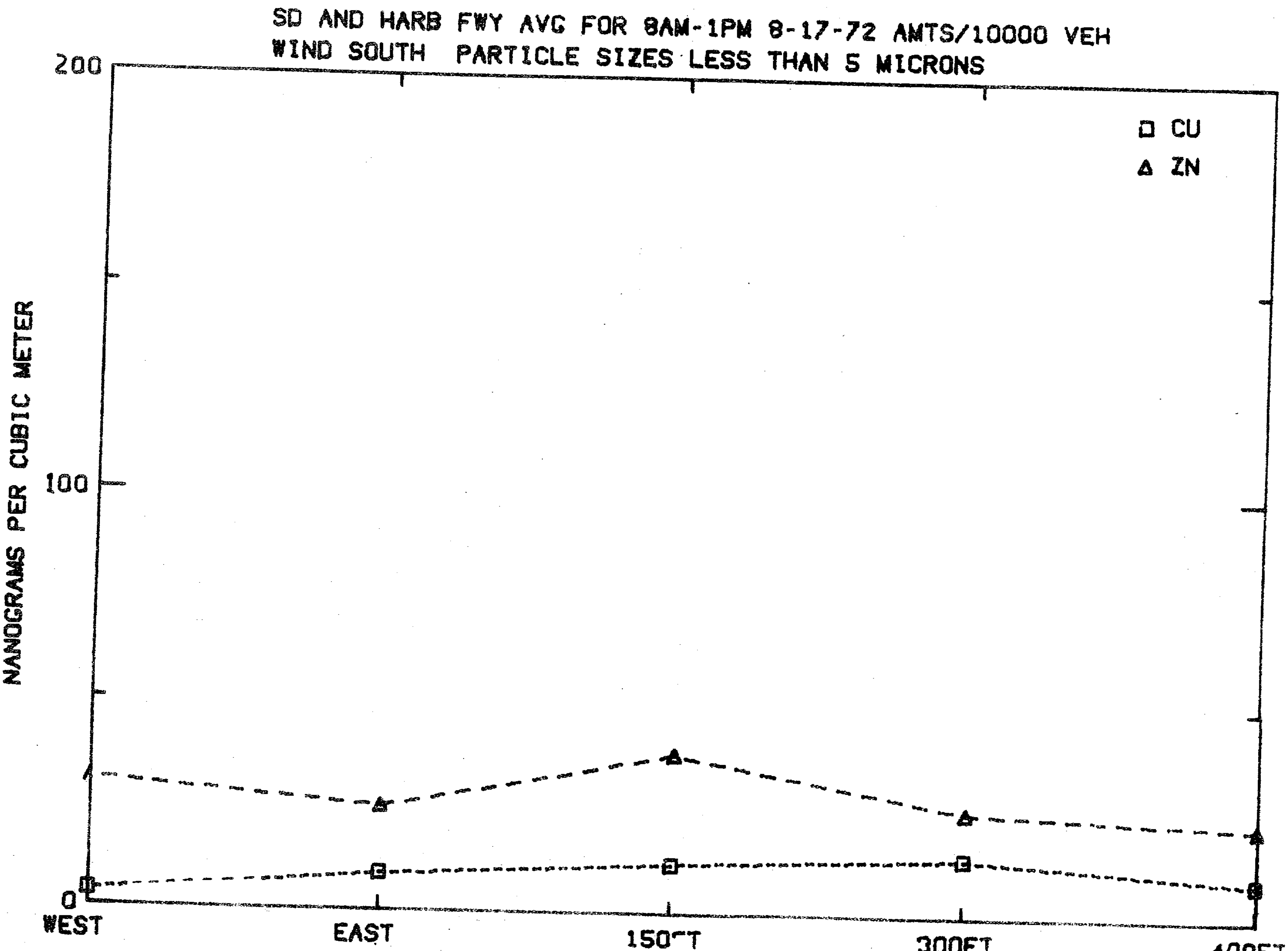

SD AND HARB FWY AVG FOR 8AM-1PM 8-17-72 AMTS/10000 VEH
WIND SOUTH PARTICLE SIZES LESS THAN 5 MICRONS
200
100
0
NANOGRAMS PER CUBIC METER
CU
ZN
WEST
EAST
150FT
300FT
400FT

FIGURE 15

TABLE 3

Elemental Content of Freeway Particulates

(Normalized to Lead)

WIND	>2 mi/hr	CALM	AVERAGE	>2 mi/hr	AVERAGE
D_{eff}	<5μ	<5μ	< 5μ	> 5μ	ALL SIZES
Hours Sampled	50 hrs.	22 hrs.	72 hrs.	32 hrs.	
ELEMENT					
Al	NA	NA	NA	0.17	>0.03
Si	> 0.06	>0.06	>0.06	0.88	>0.20
P	NA	NA	NA	<0.006	NA
S	> 0.11	>0.04	>0.09	<0.016	>0.07
Cl	> 0.01	>0.04	>0.02	0.09	> 0.026
K	<0.006	0.007	0.004	0.017	0.007
Ca	0.03	0.03	0.03	0.44	0.11
Fe	0.06	0.03	0.05	0.74	0.19
Cu	0.002	0.006	0.003	0.014	0.005
Zn	0.010	0.02	0.013	0.08	0.024
Br	0.33	0.33	0.33	0.19	0.30
Pb	≡ 1.000	≡ 1.00	≡ 1.00	≡ 1.00	≡ 1.00

NA = not available

Elements enclosed in boxes represent only Stages #3 plus #4, excluding particles smaller than 0.5μ. Thus, all values must be considered lower limits. This is especially serious for S and Cl, suspected combustion products.

(The rest of this section consisted of an attempt to identify sources for major components of the observed aerosol. First, we discussed what would be expected from combustion of gasoline, and then discussed other possible sources. Reasonable agreement between automotive sources and values in Table III was achieved, although no great confidence can be placed in the quantitative values).

III. DISPERSAL OF FREEWAY PARTICULATES

The underlying purpose of all of this work was to determine the influence of freeway traffic on air quality. In order to accomplish this, it is necessary to examine the dispersal of freeway generated particulates both into near-freeway locations and into areas remote from freeways. This project is made possible by knowledge gained on elemental content and particle size in the previous section. Once a reasonably accurate determination has been made of elements that can be used to represent types of freeway particulates, the dispersal of these elements into near-freeway areas can be followed by taking air samples at these locations and looking at the magnitude of the tracer elements. The project is made more complicated by the fact that various freeway sources tended to generate particles of widely varying size distributions. For example, the lateral dispersal of lead contains both contributions from large size particulates that may have been re-entrained in deposits in the exhaust system as well as contributions of smaller diameter particulates that are probably the result of combustion taking place at that instant. Naturally, each size range will have different dispersal properties, if for no other reason than sedimentation rates, although other mechanisms also appear to be operating.

As has been described in the introduction, sampling stations were distributed on both sides of each freeway site. Lateral extension ranged up to about 550 ft from the median strip. Since the upwind value of lead was generally much less than that downwind of the freeway, since lead is an important element for health effects, since lead was, of all the elements, most highly correlated with freeway traffic, and since lead is generally accepted as a tracer of automotive exhaust, this element was followed most closely as a function of distance from the freeway and as a function of particle size. Bromine was also followed, and generally, these are plotted on the same graph, as is the ratio of bromine to lead. This will hopefully provide information on whether aging, (involving bromine loss) perhaps in the exhaust deposits, has taken place.

The freeway sites will now be treated individually, since one of the purposes of this report is to examine the influence of freeway configuration on particulate dispersal. (The data presented in the full text is summarized in section III.D). (Examples of the three major types of plots are included in the following pages.)

SAN DIEGO AND HARBOR FWY 8/16/72.8/17/72 WEST EDGE
PARTICLE SIZES LESS THAN 5 MICRONS

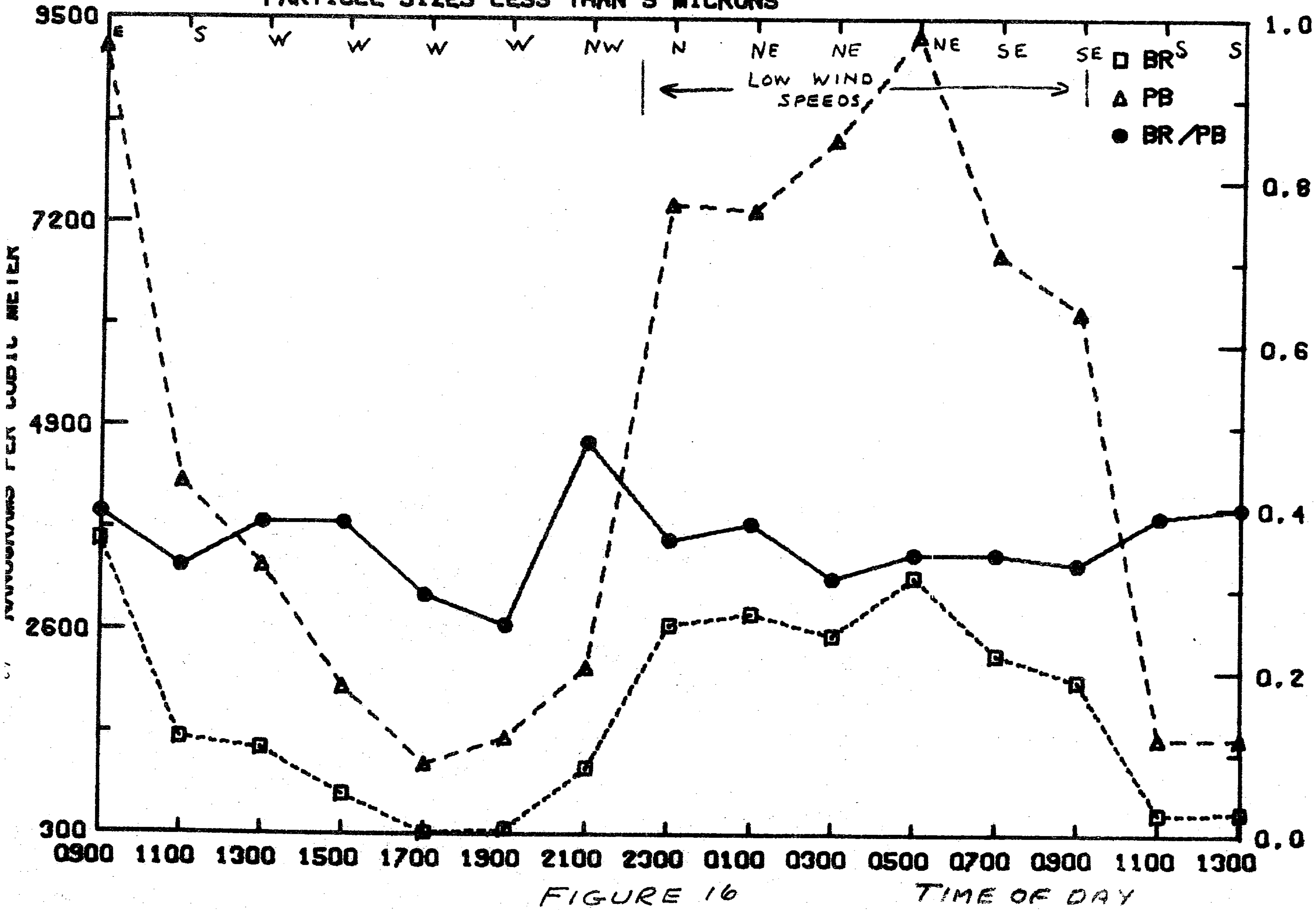


FIGURE 16

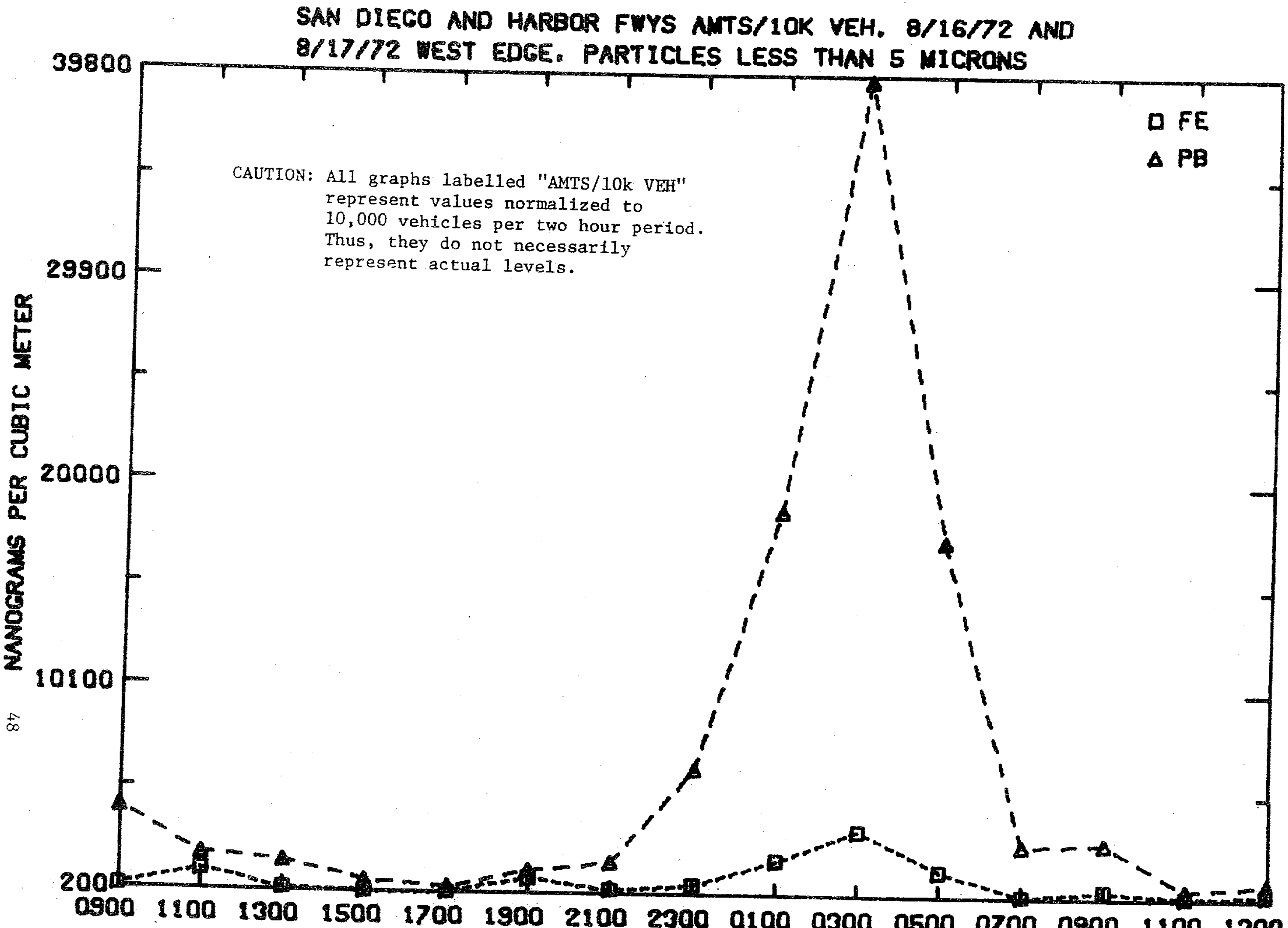

SAN DIEGO AND HARBOR FWYS AMTS/10K VEH. 8/16/72 AND
8/17/72 WEST EDGE. PARTICLES LESS THAN 5 MICRONS
FE
PB
CAUTION: All graphs labelled "AMTS/10k VEH" represent values normalized to 10,000 vehicles per two hour period. Thus, they do not necessarily represent actual levels.
39800
29900
20000
10100
2000
NANOGRAMS PER CUBIC METER
0900 1100 1300 1500 1700 1900 2100 2300 0100 0300 0500 0700 0900 1100 1300
TIME OF DAY

FIGURE 21

SAN DIEGO AND HARBOR FWYS. AMTS/10K VEH. AVERAGED OVER STRONG WESTERLY WINDS.LESS THAN 5 MICRONS

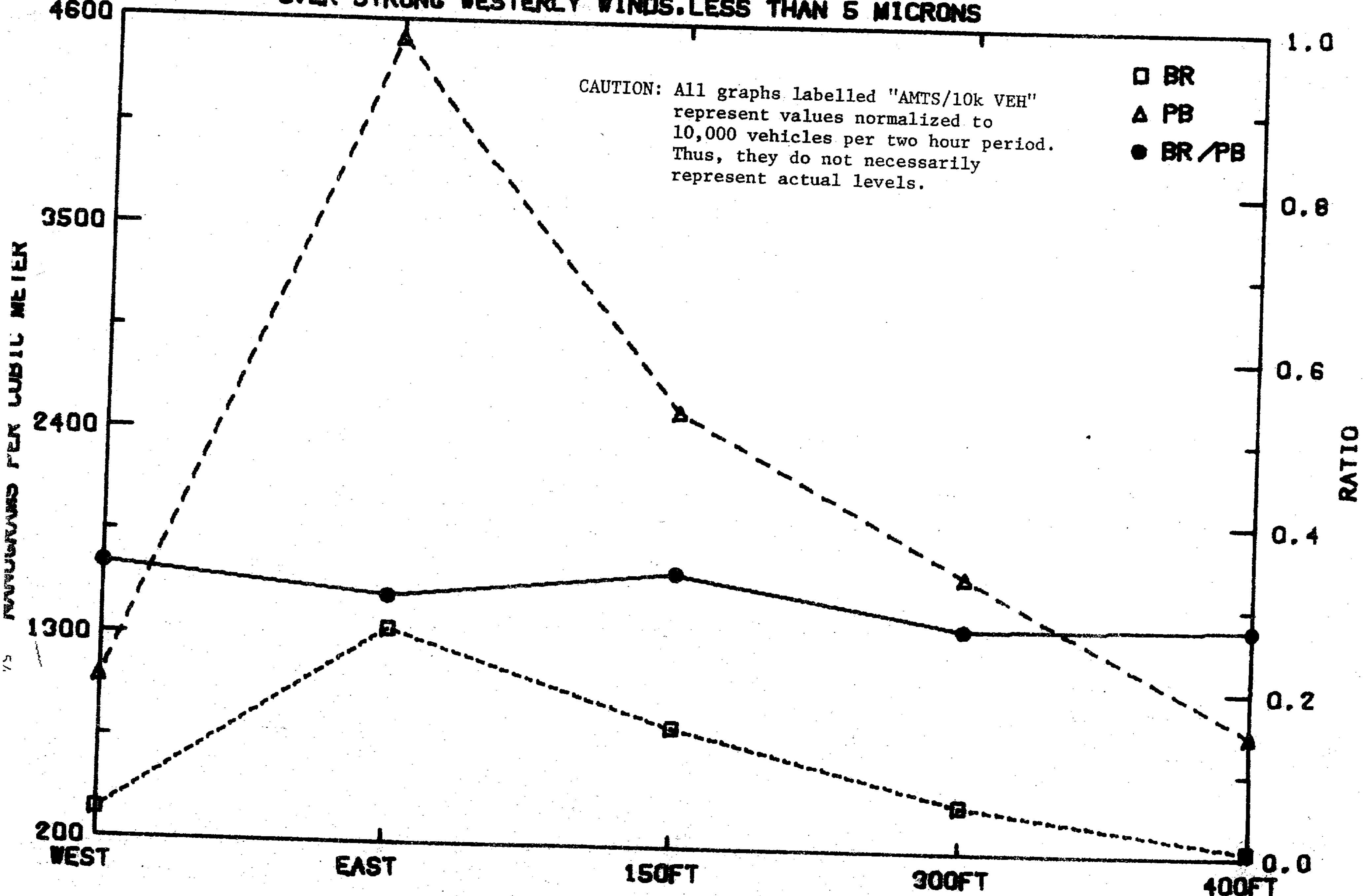


FIGURE 26 a

D. Effect of Freeway Configuration

The lateral dispersion plots for all four sites, normalized to a traffic flow of 5,000 vehicles/hr, provide a method for comparing the effect of freeway configuration on particulate levels in near freeway vicinities. All two hour periods for which the wind was strong enough to provide good ventilation of the freeways (generally > 2 mi/hr, averaging out for all sites at about 6 to 7 mi/hr), the FWY, WIND category of Section II, were summed over Stages #3, #4, and the after filter and averaged. This represents particles $<5\mu\ D_{eff}$ for $\rho \simeq 1$. Upwind values were subtracted, and the values were calculated for the downwind locations on the freeway, closest to the edge of the right of way, and 200 ft. from the edge of the right of way. From the center of the freeway, these locations correspond to displacements of approximately 90 feet, 130 feet, and 330 feet respectively. The values are given in Table 7 .

The values in brackets are obtained by setting the average upwind lead value to zero. This was included to correct for the high upwind lead values seen during the 8/14 - 8/17 sampling period, caused by placement of the upwind sampler in a location still influenced by freeway induced turbulence and wind fluctuations (∿30 ft. from the edge of the roadbed). This procedure is not warranted at other times, although it makes only a minor difference. The rate of decay of the lead values at Site #3, the at-grade section, during the August sampling and the very low upwind values at Site #4, the fill section, during the June sampling (when the upwind station was farther from the freeway) confirm this effect. Therefore, in our opinion, the true upwind value at Site #4 is probably negligible. The true upwind value at Site #3 is probably not negligible, due to the proximity upwind of the Harbor freeway. Estimating the effect of this freeway, and extrapolating the diffusion curve obtained from the Site #3 data, we estimate that about 50% of the upwind amount is due to the influence of the San Diego Freeway and 50% due to all other causes. These "best estimate" values are given in Table 8.

By examining the individual two-hour plots, we can estimate the variance in these enhancements under FWY, WIND conditions. In general, the reproducibility is extraordinarily good, and 50% confidence limits can be set conservatively at ± 30% of the above values within a given sampling period.

TABLE 7

The Effect of Freeway Configuration on Lead Levels of Particles < 5μ D_{eff} (Data)

(WIND > 3 kts.)

Site, Date	WIND	On Freeway (90 ft)	Right of Way (130 ft)	200 Feet (330 ft)	400 Feet (530 ft)
		LEAD, μg/m³, 5,000 v/hr			
Site #1, SM, 6/72 (cut section)	Parallel	4.94 (5.10)	0.85 (1.01)	0.30 (0.46)	
Site #2, Harb, 6/72 (cut section)	Transverse	4.57 (4.75)	1.72 (1.90)	0.26 (0.44)	
Site #4, SD, 6/72 (fill section)	Transverse	6.00 (6.05)	2.65 (2.70)	2.15 (2.20)	
Site #4, SD, 8/72 (fill section)	Transverse	1.60 (3.60)	0.0 (2.00)	2.00 (4.00)	1.50 (3.5
Site #3, SDH, 8/72 (at grade)	Transverse	3.40 (4.60)	2.50 (3.70)	0.80 (2.00)	-0.10 (0.8

Values in brackets assume zero upwind lead value.

Values without brackets are obtained by subtracting the lead value at the upwind station.

TABLE 8

The Effect of Freeway Configuration on Lead Levels of Particulate < 5μ D_{eff}

(Best Estimate)

(WIND > 3 kts.)

Site, Date	WIND	LEAD, μg/m³, 5000 v/hr On Freeway (90 ft)	Right of Way (130 ft)	200 Feet (330 ft)	400 Feet (530 ft)
Site #1, SM, 6/72 (Cut section)	Parallel	4.94	0.85	0.30	
Site #2, Harb, 6/72 (Cut section)	Transverse	4.51	1.72	0.26	
Site #4, SD, 6/72 (Fill section)	Transverse	6.00	2.65	2.15	
Site #4, SD, 8/72 (Fill section)	Transverse	3.60	2.00	4.00	3.50
Site #3, SDH, 8/72 (at grade)	Transverse	4.00	3.10	1.40	0.35

The difference at 200 ft for Site #4 between the June and August periods seems to represent a real effect, possibly due to weather differences. Since, within each sampling period, the values were consistent, averages were not taken by weighting with the relative number of measurements in the June and August periods, but rather a straight average. The two cut sections, which are in remarkable accord when one considers that at Site #1, the wind was almost along the freeway while at Site #2, the wind was perpendicular to the freeway, were also averaged. Thus, the net effect of configuration is obtained and presented in Table 9.

TABLE 9

Averaged Effect of Freeway Configuration on Lead Levels of Particles < 5μ D_{eff}

(WIND > 3 kts.)

CONFIGURATION	SITE #	Lead, μg/m³, 5,000 v/hr			
		On Freeway (90 ft)	Right of Way (130 ft)	200 Feet (330 ft)	400 Feet (530 ft)
Cut Section (-30 ft)	#1,2	4.7	1.3	0.3	
At-Grade Section	#3	4.0	3.1	1.4	0.35
Estimated Level (see III.E)	(for #3)	4.0†	3.4*	1.4*	0.41*
Fill Section (+ 20 ft)	#4	4.8	2.3	3.1**	

† Value derived from a mixing cell model and literature values[11,13] for emitted lead.

* Continuous line source gaussian dispersion model for stability class C, at-grade section.

** At this location, the average lead level for the 24 hour period 8/14/72 - 8/15/72, 14:30 to 14:30 was 10 μg/m³.

Mechanisms that could account for such an effect will be considered in the next section, but a few comments are worthwhile. The embankments of both cut-section freeways were heavily planted. Ivy dominated most of the slope at Site #1, with a dense thicket of bushes $\sim$ 20 ft high at the crest of the embankment hard against the right-of-way fence on both sides. Site #2 was similarly planted, with eucalyptus and bushes extending higher than 30 ft on the downwind edge. Site #3 had only ground cover (ice plant) although some trees were present in an open pattern in the upwind golf course. Site #4 had a dense thicket of bushes at the right-of-way fence on the upwind side, but very little except ice plant on the downwind side. Sites #1, #2, and #4 had residential neighborhoods with some trees and mostly one or (at Site #1) two story houses in the near freeway vicinities. To separate the effect of the planting from the freeway configuration would be a great mistake. The thickets were quite dense, and effectively cut the wind in their lee. By the time one had moved to 200 ft, however, the wind had, in all cases, achieved values less than but close to the on-freeway values, although wind direction (especially at Site #1) was more variable.

E. Correlation of Observed Lead Levels with Automotive Exhaust

From the literature,[11,12] one finds that a reasonable value for production of airborne lead particulate is about 60 mg/mi, or about 36% of the amount of lead expended per mile of travel. From measurements taken during this program, one can estimate that about 80% of this is emitted in sizes <5μ, or about 48 mg/mi. An attempt will now be made to correlate this emission value with observed levels.

Assume that the height of the freeway volume heavily mixed by vehicular traffic is 3.5 m and the width 60 m. It should be reiterated that no evidence of any sharp discontinuity in lead levels versus height was observed in the one measurement taken at Site #1, the cut section, so that the arbitrary 3.5 mixing height has no justification from this study. The quasi-exponential fall off mentioned in Section III.C did have its half value at between 10 and 15 feet, although this study is hardly definitive. In one mile (1600 m) one has a volume of $2.9 \times 10^5 m^3$ of air. Assuming 5000 automobiles/hr. traveling at 60 mi/hr., one would have an average of 83 cars in this volume, resulting in emission of 4.0 gms. of lead particulate in the <5μ size range. This would result in an average value of 12 $\mu g/m^3$ throughout this volume in one minute, assuming zero wind velocity.

Since the average wind in the FWY, WIND condition was ∿6.5 mi/hr. or 3.1 m/sec., the mixing volume would be laterally displaced by one freeway width every 20 seconds, or three times/minute. Thus, the average lead level should be about 4.0 $\mu g/m^3$, if no diffusion takes place. This value is in reasonable accord with the measured values in the on-freeway location.

The agreement between the predicted and measured values of lead shown in Table #15 indicates that the particulate production factors given in the literature[11,13] are applicable to freeway conditions. This fact greatly eases the problem of predicting lead levels in near freeway vicinities for at-grade configurations.

One can go farther than this simple "box" model for lead levels. Theoretical plots of particulate dispersion from freeways were determined from a continuous line source ground boundary equation with settling velocities superimposed to give the corrected distributions. Pasquill stability class C (moderately unstable) was chosen as best representing the average condition used in the Freeway, Wind data sub-set, although considerable leeway is allowed by the crude stability determinations used in this study.

For the first attempt, values derived from the calculation were normalized at 90 feet to the values obtained from the "box" model, and the results for the at-grade section, Site #3, shown in Table 15. The excellent agreement with observation is very encouraging.

The next attempt was to use this model to attempt to understand the strange behavior observed at the fill section, Site #4. No attempt was made to perform quantitative calculations in this difficult configuration, since such boundary conditions are not able to be properly introduced at this time.

The 24 ft. site is immediately downwind of the freeway edge and is isolated from the smaller particles. Noting that stability A is most unstable, D neutral, and F most stable, particle size as a function of distance for lines of constant stability shows in detail the effects of vertical mixing on the distributions.

The 1.0 micron particle plots show that an inversion with moderate wind stabilities of E or F will cause large quantities of particulates to be carried downwind, with peaks at $\sim$1 mile. (Figure 62)

The 100 micron plots show the expected quasi-gaussian distribution for large particles. (Figure 64)

The striking distribution of the 10 micron plots show particles 'falling out' at 100 ft. for more stable cases with expected broadened peaks for unstable cases A and B. (Figure 63)

The striking downwind peaks seen in the data from the fill section, Site #4, thus have firm basis in theory. The extreme sensitivity of lead levels to stability class and the potential for dispersal at high concentrations to locations relatively far removed from a fill section freeway are important considerations in any estimate of freeway influence.

Using this simple model, one can also study the lead levels observed during periods of relatively calm winds.

The effect of calm periods is predictable, in that the mixing volume becomes very small as the wind velocity approaches zero. The value of 4.0 $\mu g/m^3$ calculated for near freeway conditions for a 6.5 mi/hr. wind rises to about 25 $\mu g/m^3$ for a 1 mi/hr. wind, in good agreement with the 30 $\mu g/m^3$ value observed at Sites #3 and #4 for winds measured at 1.0 $\pm$ 0.5 mi/hr. during the August sampling period. Unfortunately, no calm periods were sampled for Sites #1 and #2 for an on-freeway sampler, but the same value of enhancement is visible 35 feet above the freeway in Figure #54 for two successive evenings in March at Site #1. ($\sim$26 $\mu g/m^3$)

DOWNWIND GAUSSIAN PLOT 1. MICRON PARTICLES CROSS-WIND
1 KNOT AS A FUNCTION OF STABILITY

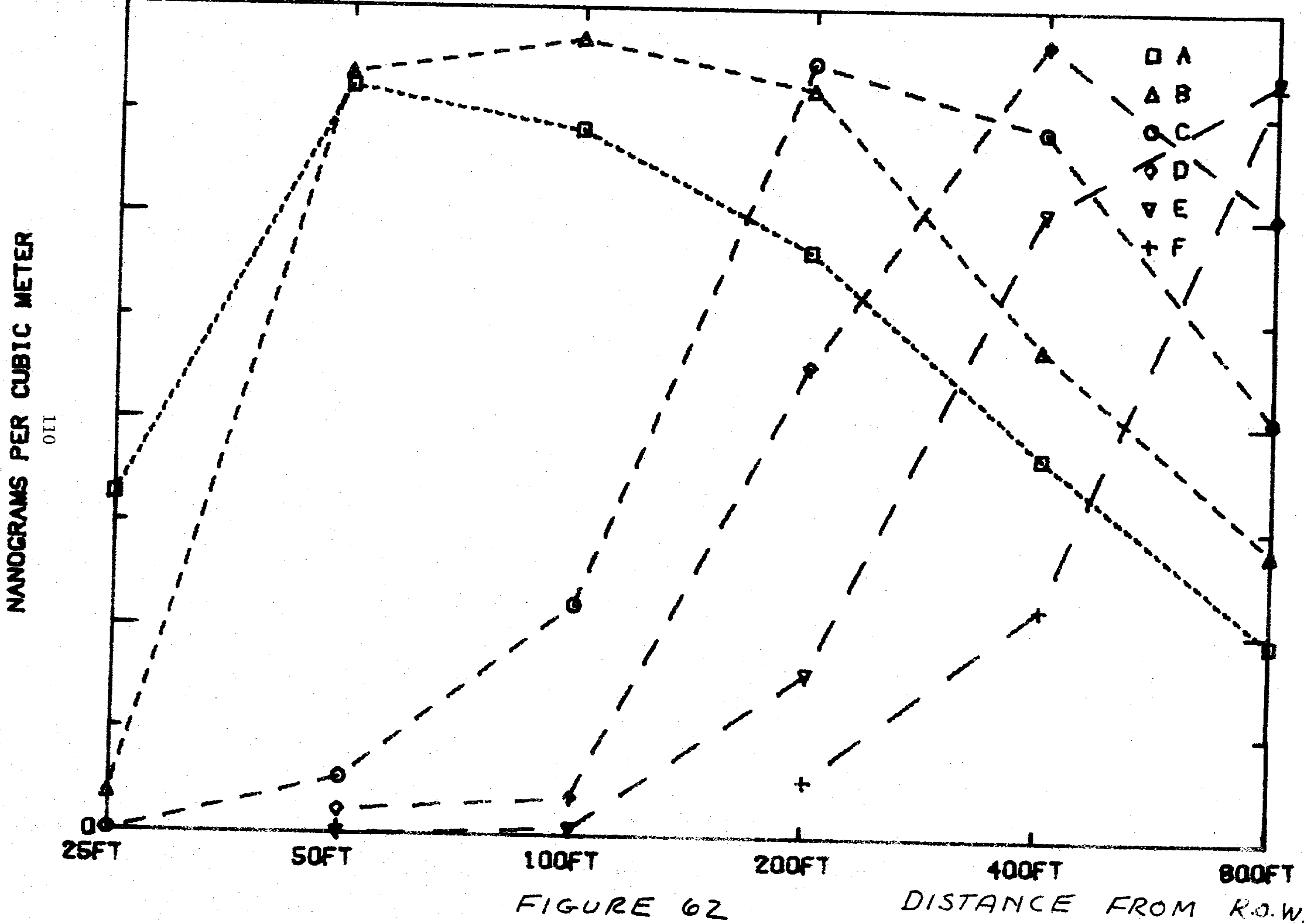


FIGURE 62

10. MICRON PARTICLES CROSS-WIND
1 KNOT AS A FUNCTION OF STABILITY

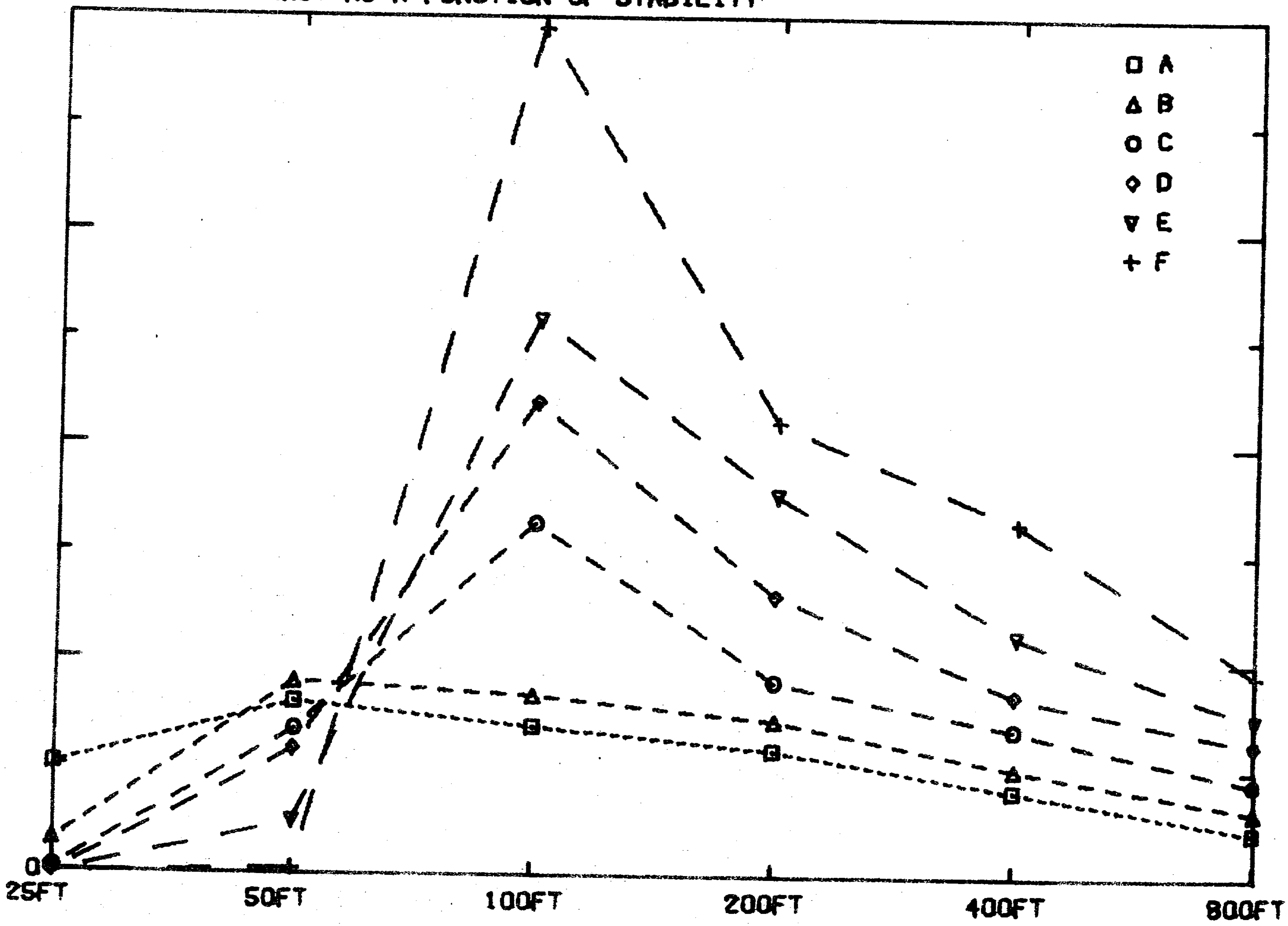


FIGURE 63 DISTANCE FROM R.O.W.

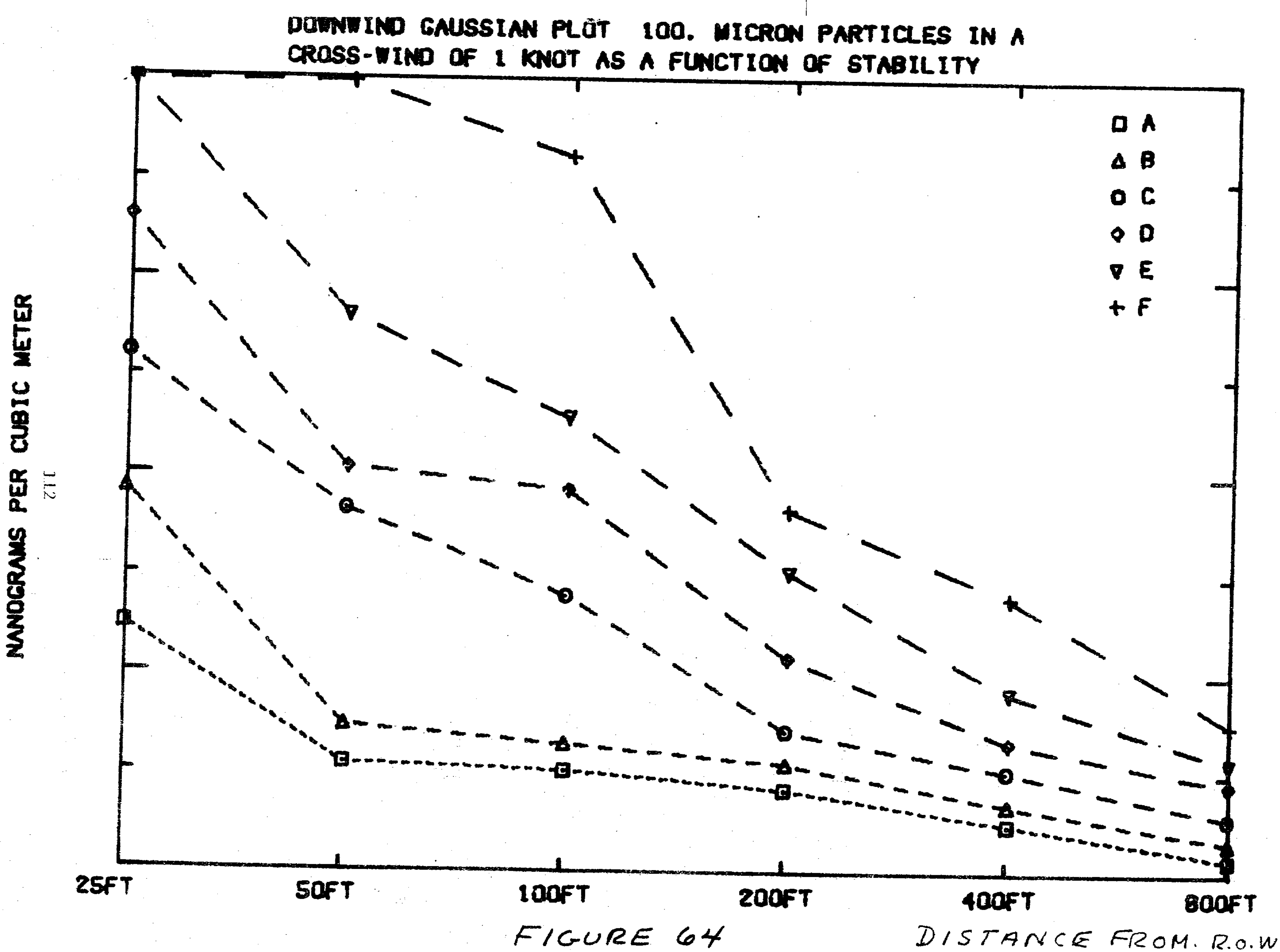

DOWNWIND GAUSSIAN PLOT 100. MICRON PARTICLES IN A
CROSS-WIND OF 1 KNOT AS A FUNCTION OF STABILITY
NANOGRAMS PER CUBIC METER
A
B
C
D
E
F
25FT
50FT
100FT
200FT
400FT
800FT
DISTANCE FROM. R.o.W

FIGURE 64

The full text version includes four appendices:

Appendix A - Operation of the collection system.

This appendix describes the impactors, how they were used, preparation of the mylar drum surfaces with paraffin to minimize bounce-off, and collection efficiency studies. (pgs. 113-126)

Appendix B - Elemental Analysis of Particulate Samples by Ion-Excited X-Ray Emission (IEXE).

This appendix describes the elemental analysis system at Davis, including a summary of elemental standards used, computer reduction codes, and interlaboratory comparisons. (pgs. 127-139)

Appendix C - Scanning Electron Microscopy Pictures (4).

Many others were taken, but reproduction is costly.

Appendix D - Trial Calculation of Automotive Sources.

This appendix describes an attempt to correlate the observed particulate matter (Table 3) with sources such as gasoline combustion, motor oil, other fluids, tires, brake lineup, brake drums, fan belts, engine and exhaust train wear, and roadbed wear. Although quantitative values must be viewed with caution, due largely to uncertainties in particulate production factors, the results appear reasonable.